EVALUATION OF VEHICLE COMPATIBILITY
IN VARIOUS FRONTAL IMPACT CONFIGURATIONS

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ABSTRACT

Light truck vehicles (LTVs), sport utility vehicles (SUVs), and vans collectively make up a growing segment of the total automotive fleet sales, particularly in the United States. The National Highway Traffic Safety Administration (NHTSA) has identified this trend and has increased the extent of its research in vehicle-to-vehicle compatibility. Additionally, vehicle compatibility concerns have also been emphasized by International Harmonization Research Activity (IHRA). Accordingly, with intention to further enhance road safety, research in the area of crash compatibility between cars and LTVs in different crash configurations is of significant importance.

This paper describes a part of ongoing research at Ford Motor Company to further investigate the effect of compatibility in SUV/LTV-to-Car crashes. Test results of SUV/LTV-to-Car crashes involving various frontal impact configurations were analyzed in order to develop test procedures and requirements to help assess vehicle compatibility. Specifically, three SUV-to-Car frontal impact configurations were assessed in the present study: full overlap collinear impact, 50% offset collinear impact, and 30-degree oblique impact. In each of the tests, both the target and bullet vehicles contained a Hybrid III 50th percentile instrumented test dummy (HIII50) for the driver and a Hybrid III 5th percentile instrumented test dummy (HIII05) for the passenger. Analysis of the tests yielded the following results: (1) Structural and occupant responses were used to help quantify the effect of mass, stiffness, and geometry, (2) A robust and repeatable vehicle-to-vehicle test procedure was proposed, and (3) Preliminary results indicated that geometric incompatibility was the dominating factor in the studied vehicle design characteristics.

1. INTRODUCTION

Compatibility concerns in vehicle-to-vehicle crashes in the United States have received considerable attention due to recent studies and publications by NHTSA and other agencies worldwide [1,2,3,4]. These concerns have been noted for the entire fleet of vehicles on the road, although government agencies and the media have concentrated on the SUVs and LTVs. The SUV and LTV market share has risen steadily during the last decade and has become a growing component of the U.S. fleet. As a group, these vehicles are generally heavier, stiffer, and have higher ground clearance compared to those of the passenger cars.

In LTV/SUV-to-passenger car frontal crashes, the potential occupant risk to the occupants in the passenger car is generally higher. This was due to the larger velocity change (ΔV) and the higher intrusion experienced by the generally lighter, smaller, and less stiff, passenger cars. However, to achieve enhanced real-world safety, reducing the aggregate potential risk of the involved occupants needs to be considered. This presents vehicle design challenges to provide self risk-reducing potential as well as partner risk-reducing potential. The partner protection issue led to several studies and investigations to help better understand the effect of vehicle design parameters such as mass, geometry, and stiffness on crash compatibility.

The present vehicle fleet differs in mass, geometry, stiffness, and many other design parameters. Vehicle compatibility has been investigated in many studies using different approaches such as real-world crash statistics, crash testing and computer modeling. NHTSA used U.S. crash statistics from the Fatality Analysis Reporting System (FARS) to determine the number of fatalities in vehicle-to-vehicle collisions [1]. Moreover, statistics from the General Estimates System (GES) were used to determine the number of vehicle-to-vehicle collisions [2]. One objective of these studies was to identify and demonstrate the extent of the problem of vehicle compatibility. Another objective was to demonstrate, through statistical analysis, the aggressivity metric as a function of vehicle mass, stiffness, and geometry. Other statistical analysis such as that conducted by Evans [5,6] indicated that mass is one of the most significant factors affecting potential risk of occupant injury in vehicle-to-vehicle collisions. His study indicated that the ratio of the injury rate in a lighter vehicle to that in a heavier one can be expressed as the power function of the mass ratio (of the heavier to the lighter vehicle). Accident data in Japan and computer modeling techniques were also used by Mizuno and Kajzer [7] to investigate the compatibility of mini cars in traffic accidents.

Most recently, Summers et al. [3] from NHTSA conducted a series of full-scale vehicle-to-vehicle crash tests to evaluate potential crash compatibility issues. Tests were conducted with four different striking vehicles representing various vehicle classes impacting a Mid-size sedan struck vehicle in both side and oblique frontal impacts. For the oblique offset crash test series, a good correlation was obtained between the driver injury measures of the struck vehicle with vehicle mass. However, NHTSA concluded that more research needed to be conducted to further understand the vehicle design parameters that effect vehicle compatibility.

In the present study, NHTSA's test procedures for the frontal oblique crash tests, as there were issues related to the repeatability and reproducibility of those crash tests, were further evaluated. Specifically, a series of vehicle-to-vehicle crash tests were conducted in various frontal impact configurations. A series of 30-degree offset oblique frontal impacts, similar to NHTSA's test configurations, were carried out to address issues associated with this test procedure. Two additional SUV-to-Car collinear frontal impact configurations, e.g., full overlap and 50% offset, were also investigated and presented in this study. Structural and occupant performances to quantify the effect of vehicle design parameters on vehicle compatibility were analyzed and reported. A robust test procedure for vehicle-to-vehicle frontal impact was also proposed to help assess vehicle compatibility.

2. VEHICLE-TO-VEHICLE CRASH TESTING

Because of the limitations associated with the statistical approach, crash testing was deemed necessary to examine the influence of vehicle mass, stiffness, structural interaction, and geometry on vehicle compatibility. Impact configuration and collision type in frontal impact were determined to be the most important factors governing vehicle performance since they directly affected how the two vehicle's structures interacted. For example, the effect of vehicle stiffness and geometry on the deformation and occupant response outcome in the struck vehicle changed significantly from a full frontal and offset collinear impact to a frontal oblique impact (in two-vehicle crashes).

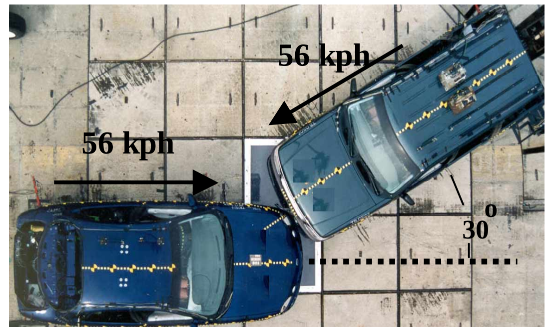


Figure 1. 30-degree oblique offset test configuration with the struck vehicle in horizontal and the striking vehicle in oblique.

NHTSA [3] conducted a series of frontal oblique vehicle-to-vehicle impact tests using a test procedure developed under NHTSA's Advanced Frontal Offset Research Program [8]. The test configuration is shown in Figure 1. Test results showed good correlations between the occupant response parameters (measured on occupants in the struck vehicle) and the striking vehicle mass and aggressivity metric (AM) defined by NHTSA as the ratio of the driver fatalities in collision partners to the number of crashes of the subject vehicle. However, it was also concluded that there were additional factors other than the mass difference that affected vehicle aggressivity. The present authors considered it difficult to extract the effects of stiffness and geometry in the oblique frontal vehicle-to-vehicle impact tests. Therefore, crash tests in various frontal impact configurations, including NHTSA's configurations, were examined in the present work.

2.1 30-degree Oblique Offset Test

In this test series, the target vehicle (T) was a four-door sedan representing an average Mid-size passenger vehicle in the fleet. This target vehicle was impacted by a series of four bullet vehicles (B): a SUV, a Small Pickup, a Mini-Van, and another Mid-size car (i.e., the same as the target). The bullet vehicles were selected to provide various potential aggressivity characteristics associated with mass, stiffness, and geometry. This selection of the vehicles was similar to that reported by NHTSA [3].

The frontal oblique tests were conducted according to the test configuration shown in

Figure 1. Both the target and bullet vehicles were moving at approximately 56 kph at the time of contact. At impact, the left side of the bullet vehicle aligned with the front center of the target vehicle, which was struck on the left front side. In all the tests presented in this paper, both the target and bullet vehicles used a Hybrid III 50th percentile male dummy for the driver and a Hybrid III 5th percentile female dummy for the passenger. The driver seat was at the mid-position while the passenger seat was full-forward. All the dummies were belted and the airbags were active. Table 1 shows vehicle test weights, relative bumper heights, initial speeds, and vehicle velocity changes. The relative bumper height was represented by the vertical distance between reference points, i.e., the center of the target vehicle's bumper and the center of the bumper of the bullet vehicle. It should be noted that a positive number indicated that the bumper of the bullet vehicle was initially above the reference point on the target vehicle.

Table 1.

Test Condition of 30-degree Oblique Vehicle-to-Vehicle Tests.

Bullet Vehicle		Small SUV	Mini-Van	Pickup	Mid-size Car
Target Vehicle		Mid-size Car			
B\Vehicle Mass	kg	2084	2040	1727	1843
T\Vehicle Mass	kg	1845	1845	1847	1849
Mass Ratio		1.13	1.11	0.94	1.00
T\Initial Velocity	kph	57.2	57.2	54.4	55.7
B\Initial Velocity	kph	56.4	56.7	56.4	56.2
T\Velocity Change	kph	56.1	55.6	51.1	52.8
B\Velocity Change	kph	49.7	50.2	54.7	53.0
Relative Bumper Height	mm	94.0	25.4	116.8	10.2

2.2 Full Frontal and 50% Offset Tests

In this test series, the target vehicle was the same Mid-size sedan used in the 30-degree oblique offset tests. The target vehicle was impacted by various bullet vehicles (i.e., two different SUVs) in two different frontal impact configurations (i.e., full frontal and 50% offset). The test setup is illustrated in Figure 2. The first bullet sport utility vehicle, SUV I, was selected to be the same as that used in the oblique offset test configuration listed in Table 1 (designated as "Small SUV"). This provided the opportunity to evaluate the performance of the target vehicle and its occupants when struck by the same bullet vehicle in three different frontal impact configurations. The second bullet sport utility vehicle, SUV II, was selected to be heavier and stiffer than SUV I. However, its rail height from the ground was roughly equal (therefore, roughly geometrically compatible) to that of the target vehicle. This selection was made to isolate the effects of geometry. Figure 3 shows the geometrical alignment of the bumpers and frame rails of the two bullet vehicles, SUV I and SUV II, with that of the target vehicle. Table 2 shows vehicle test weights, initial speeds, and velocity changes for both full frontal and 50% offset impact tests.

Full frontal collinear

50 % offset collinear

Figure 2. SUV-to-Car test configurations.

The target vehicle was initially at rest in both the full frontal and 50% offset impact tests. The bullet vehicle velocity was selected based on relative masses involved, i.e., the velocity was mass-adjusted to result in approximately 56 kph barrier-equivalent velocities for the target vehicle. The same dummies, restraint systems, and seating positions used in the oblique offset tests were also used for this series of tests.

SUV I-to-Car **SUV II-to-Car**

Figure 3. Geometrical differences between bullet and target vehicles.

Table 2.

Test Condition for Full Frontal and 50 % Offset SUV-to-Car Impacts

Bullet Vehicle		SUV I	SUV II	SUV I	SUV II
Target Vehicle		Mid-size Car			
Impact Configuration		**Full frontal**		**50 % Offset**	
Bullet/Target Speed	kph	96.2/0	93.3/0	96.1/0	92.8/0
B\Vehicle Mass	kg	2132	2694	2131	2680.2
T\Vehicle Mass	kg	1867	1777	1859	1781.3
Mass Ratio		1.14	1.52	1.15	1.50
B\Velocity Change	kph	44.2	35.3	44.3	31.9
T\Velocity Change	kph	52.0	58.0	51.7	60.9

3. TEST RESULTS AND DISCUSSIONS

When considering lighter vehicle-to-heavier vehicle impacts, the lighter vehicles experience higher velocity changes while heavier vehicles experience lower velocity changes. The velocity changes experienced by both vehicles during impact were calculated and presented in Tables 1 and 2 for the oblique offset and collinear frontal impact tests, respectively. Since both the target and bullet vehicles were subjected to the same impact durations, the occupants in the lighter vehicle experienced a higher level of acceleration. Occupant responses such as resultant head acceleration, chest acceleration, chest deflection, and femur compression loads were measured for both the driver and passenger dummies in both vehicles during impact. The aforementioned occupant responses were normalized by their corresponding occupant response injury assessment reference values (IARVs) reported by Mertz [9].

3.1 Dummy Response in 30-degree Oblique Offset Tests

Table 3 summarizes the driver (HIII50) responses for both the target and bullet vehicles along with related IARVs. Similarly, Table 4 summarizes the passenger (HIII05) responses for both the target and bullet vehicles. The normalized, derived occupant responses, such as the 36ms-based Head Injury Criteria (HIC36), 3ms-based accumulative chest acceleration, chest deflection, and the maximum femur compression forces were plotted for all four oblique offset tests. Test results, in terms of occupant responses, were plotted on the x-axis in a descending order of the aggressivity metric values associated with the bullet vehicle used in each test. The largest AM was associated with the Small SUV, and the smallest AM was associated with the Mid-size car (as reported in Reference 3). The aggressivity metrics were quantified as the ratio of the driver fatality in collision partners to the total number of crashes of the subject vehicle for various subject vehicle categories.

Figure 4 shows the comparison of the driver dummy responses in the target vehicle for the four oblique offset crash tests. Similar comparisons for the passenger dummy responses in the target vehicle are shown in Figure 6. The comparisons of the driver and passenger dummy responses for the bullet vehicle in these tests are shown in Figures 5 and 7, respectively. The occupant responses were normalized by the IARVs.

For the driver in the target vehicle as shown in Figure 4, there was a general trend of increasing normalized occupant responses with increasing aggressivity metric. With the exception of the Small Pickup, a very similar trend is observed with increasing weight. The weight of the Small Pickup was the lowest of the bullet vehicles used in the tests. It was also observed for the driver of the target vehicle, that the Small SUV produced significantly higher occupant responses than those associated with the Mini-Van (although the difference between their weights was only 44 kg c.f., Table 1). These two observations indicated that there might be factors other than the weight that influenced the aggressivity metric of these bullet vehicles. In such a complicated test configuration, it was difficult to extract the effect of the individual design parameters such as mass, stiffness, and geometry. The Small SUV produced occupant responses for the driver in the target vehicle that exceeded the cited IARVs.

All of the occupant responses for the occupants of the bullet vehicles were below the IARVs. The vehicle design parameters of the bullet vehicle were considered to have little effect on the related occupant responses (see Figures 5 and 7). However, they had a major influence on response outcome of occupants of the struck target vehicle, in particular the driver. The driver occupant responses in the Mid-size bullet car were slightly higher compared to the responses produced by the other three striking vehicles. Since the target and bullet vehicles were identical in this case and fully compatible, the velocity change experienced by the occupants of the bullet vehicle was the same as that of the target vehicle (see Table 1). This level of velocity change was considered to have caused the slightly higher occupant responses compared to the related driver's responses of the other bullet vehicles. Figure 8 shows selected results of Figure 4 plotted with the descending order of the relative bumper height (representing potential geometrical incompatibility). The occupant responses produced by the Mid-size vehicle striking the same Mid-size target vehicle were the lowest among the four tests. Presenting the results in this manner confirmed that aligning the geometrical height of the rails or bumpers of both vehicles, in vehicle-to-vehicle impact, was an important design feature to achieve compatibility. The significantly higher occupant responses experienced by the driver of the target vehicle struck by the Small SUV was attributed to a combination of mass and geometry effects.

Table 3.

Driver Dummy Responses in Target and Bullet Vehicles in the Oblique Offset Tests

			Occupant Responses for Driver in Target Vehicle				**Occupant Responses for Driver in Bullet Vehicle**			
Bullet Vehicle		IARV	Small SUV	Small Pickup	Mini-Van	Mid-Size Car	Small SUV	Small Pickup	Mini-Van	Mid-Size Car
Target Vehilce		Ref[9]	Mid-Size Car				Mid-Size Car			
Occupant Responses			***Driver 50th Percentile Male***				***Driver 50th Percentile Male***			
HIC		1000	931	377	693	318	234	286	221	549
Chest Acceleration	G	60	119	32	37	30	36	35	30	48
Chest Deflection	mm	63	56	16	21	15	25	22	16	30
L/Femur Compression	N	10,000	22347	2970	2713	2730	2608	6653	1738	3652
R/Femur Compression	N	10,000	8153	4784	4519	4561	5241	6027	2635	777

Table 4.

Passenger Dummy Responses in Target and Bullet Vehicles in the Oblique Offset Tests

			Occupant Responses for Passenger in Target Vehicle				**Occupant Responses for Passenger in Bullet Vehicle**			
		IARV	Small SUV	Small Pickup	Mini-Van	Mid-Size Car	Small SUV	Small Pickup	Mini-Van	Mid-Size Car
Target Vehicle		Ref[9]	Mid-Size Car				Mid-Size Car			
Occupant Responses			***Passenger 5th Percentile Female***				***Passenger 5th Percentile Female***			
HIC		1000	355	89	385	388	76	146	24	83
Chest Acceleration	G	60	36	24	35	28	31	35	21	30
Chest Deflection	mm	52	16	7	10	9	20	23	12	19
L/Femur Compression	N	6,800	3734	3750	3381	2824	2138	2790	1730	1910
R/Femur Compression	N	6,800	1511	1414	850	608	1601	1697	1399	1753

3.2 Dummy Response in Full Frontal and 50% Offset Tests.

For both full and 50% overlap frontal impacts, the measured occupant responses for the drivers and the passengers of tested vehicles are presented in Tables 5 and 6, respectively. Again, the occupant responses were normalized by the IARVs and presented graphically in Figures 9 – 12. As indicated in Table 2, the bullet vehicle, SUV II, was heavier than the SUV I, but its rail height was geometrically compatible with that of the target vehicle (see Figure 3). Figure 9 indicates that the driver dummy responses in the target vehicle struck by the SUV II were substantially less than those associated with the strike by the SUV I and were attributed to the better geometrical matching of the SUV II rails with those of the target vehicle. As observed from Table 2, the tests conducted with SUV II in both the full frontal and 50% offset induced velocity changes of 58 kph and 61 kph compared

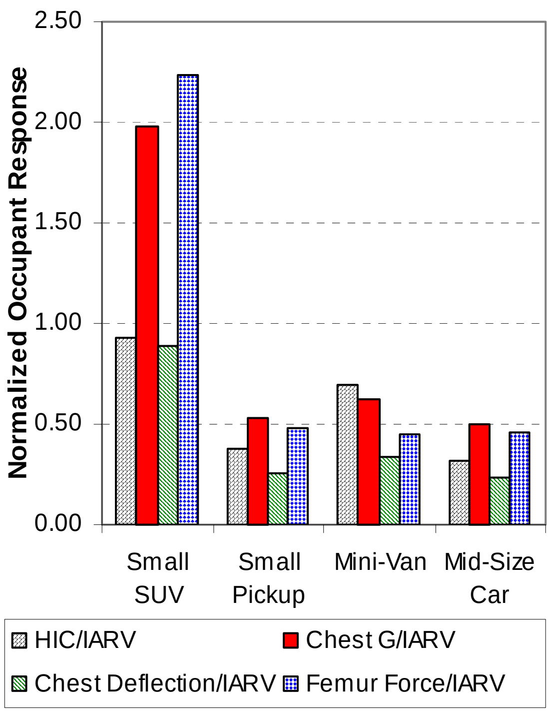


Figure 4. Occupant responses for driver of the target vehicle.

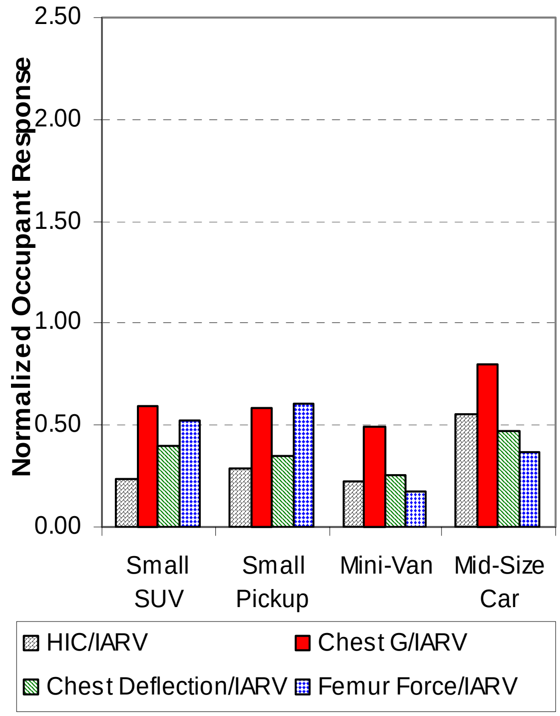


Figure 5. Occupant responses for driver of the bullet vehicle.

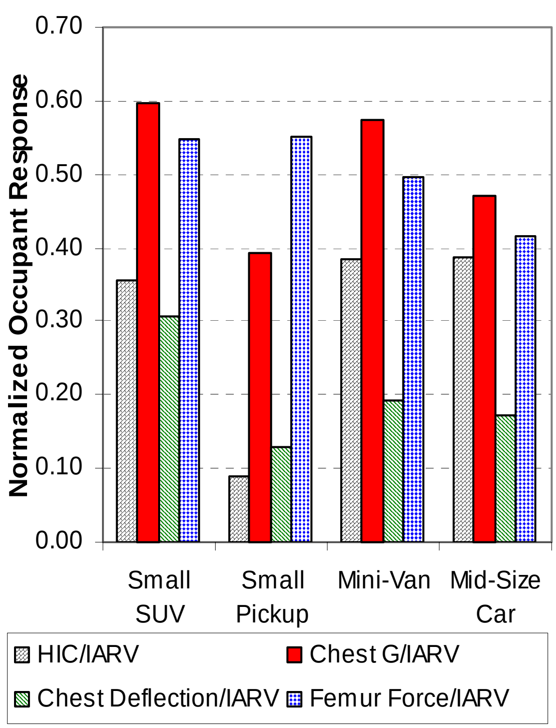


Figure 6. Occupant responses for passenger of the target vehicle.

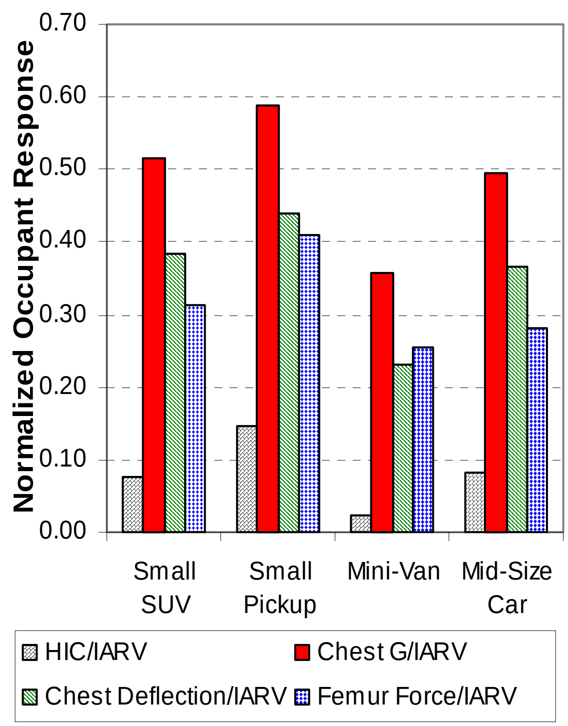


Figure 7. Occupant responses for passenger of the bullet vehicle.

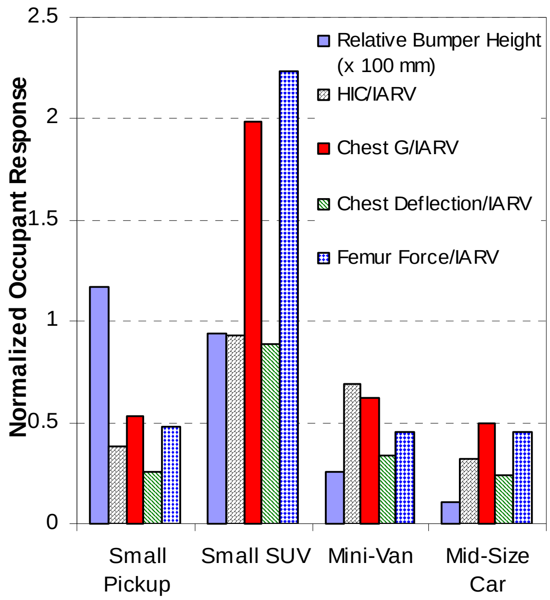


Figure 8. Occupant responses for driver of the target vehicle.

to those of 52 kph and 51.7 kph in the SUV I test, respectively. Due to a higher velocity change, it was expected that the occupant response outcome of the target vehicle occupants struck by SUV II to be higher than those of SUV I. However, the responses shown in Figures 9 and 11 for the driver and passenger in the SUV II tests were still generally better. Similar trends were also observed for the driver and passenger of the bullet vehicles in both the full frontal and 50% offset tests (see Figures 10 and 12).

Pre- and post-crash dimensional analyses on the driver center section for cabin intrusion profile were conducted to help assess the effect of mass, stiffness, and geometry on the structural performance of the target vehicle. It was expected that intrusions of the target vehicle struck by heavier and stiffer vehicles would be greater than if struck by lighter vehicles. The comparison shown in Figure 13 indicated that intrusions, from the cowl top to the floor panel at the driver center section caused by SUV II were significantly lower than those caused by SUV I. This observation held true for both full frontal and 50% offset impact tests. It was clear that the reduced structural interaction (due to the geometrical incompatibility) caused SUV I to override the target vehicle; this caused significant cowl intrusions at the windshield level. These findings served as further evidence that matching the front rail heights for the target and bullet vehicles was a very important design feature for compatibility.

Table 5.

Driver Dummy Responses in Target and Bullet Vehicle in the Full Frontal and 50 % Offset Tests

			Occupant Responses for Driver in Target Vehicle				**Occupant Responses for Driver in Bullet Vehicle**			
Impact Configuration			Full Frontal		50 % Offset		Full Frontal		50 % Offset	
Bullet Vehicle			SUV I	SUV II	SUV I	SUV II	SUV I	SUV II	SUV I	SUV II
Target Vehilce		IARV	Mid-Size Car				Mid-Size Car			
Occupant Responses		Ref[9]	*Driver 50th Percentile Male*				*Driver 50th Percentile Male*			
HIC		1000	531	757	386	443	327	166	148	174
Chest Acceleration	G	60	52	43	49	39	47	29	30	27
Chest Deflection	mm	63	45	32	43	34	34	28	19	25
L/Femur Compression	N	10,000	3576	2904	5716	4038	6783	1819	3376	3193
R/Femur Compression	N	10,000	5235	3309	6837	3193	3821	765	2793	3162

Table 6.

Passenger Dummy Responses in Target and Bullet Vehicle in the Full Frontal and 50 % Offset Tests

			Occupant Responses for Passenger in Target Vehicle				**Occupant Responses for Passenger in Bullet Vehicle**			
Impact Configuration			Full Frontal		50 % Offset		Full Frontal		50 % Offset	
Bullet Vehicle			SUV I	SUV II	SUV I	SUV II	SUV I	SUV II	SUV I	SUV II
Target Vehicle		IARV	Mid-Size Car				Mid-Size Car			
Occupant Responses		Ref[9]	*Passenger 5th Percentile Female*				*Passenger 5th Percentile Female*			
HIC		1000	349	649	125	536	307	201	72	157
Chest Acceleration	G	60	40	33	29	31	40	30	26	28
Chest Deflection	mm	52	24	25	17	28	21	30	13	30
L/Femur Compression	N	6,800	4977	5688	3109	6030	2366	1983	2126	2224
R/Femur Compression	N	6,800	4323	4710	1939	2486	2695	1147	2059	98

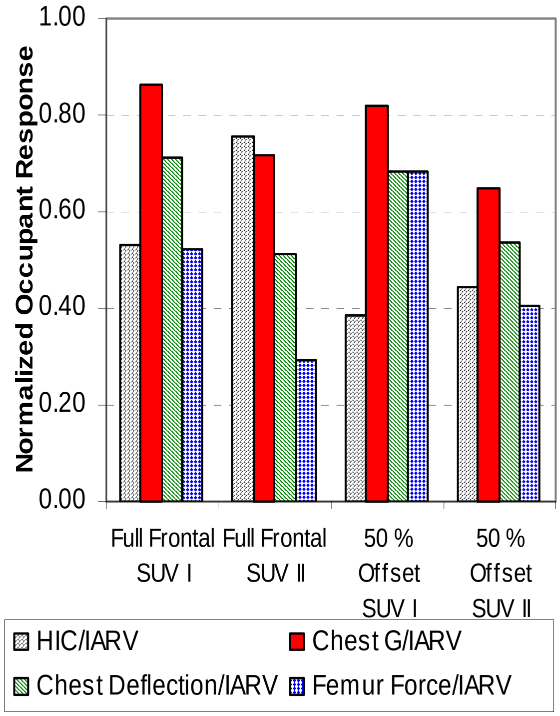


Figure 9. Occupant responses for driver of the target vehicle.

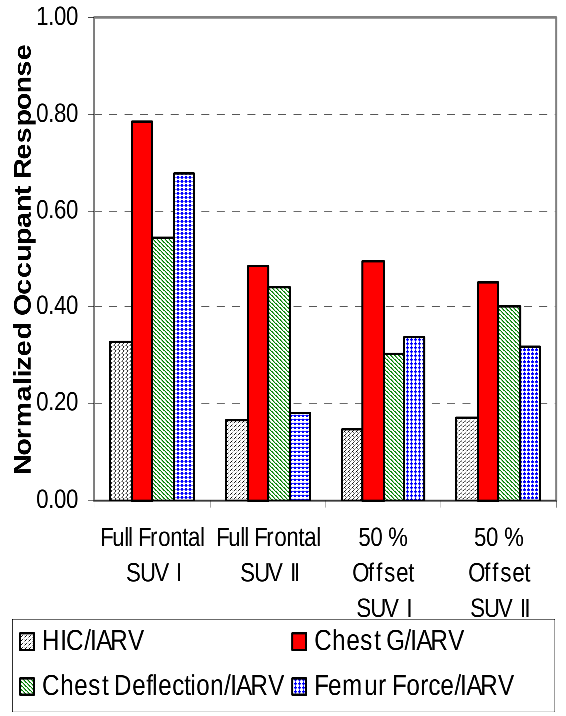


Figure 10. Occupant responses for driver of the bullet vehicle.

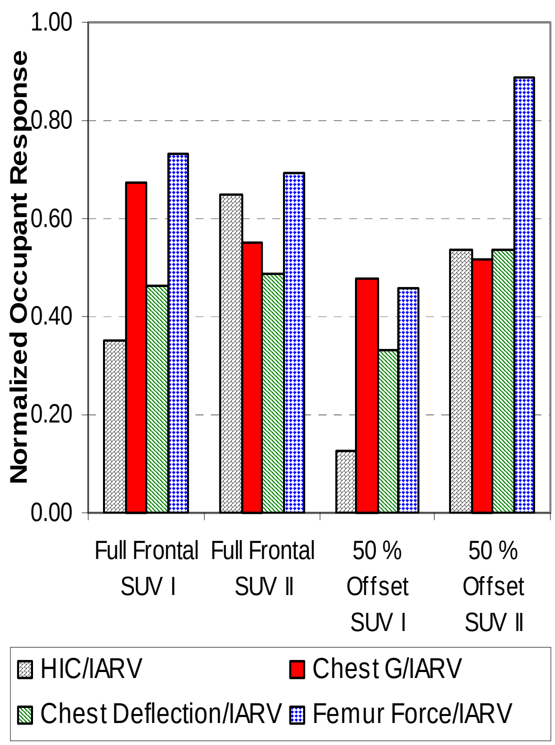


Figure 11. Occupant responses for passenger of the target vehicle.

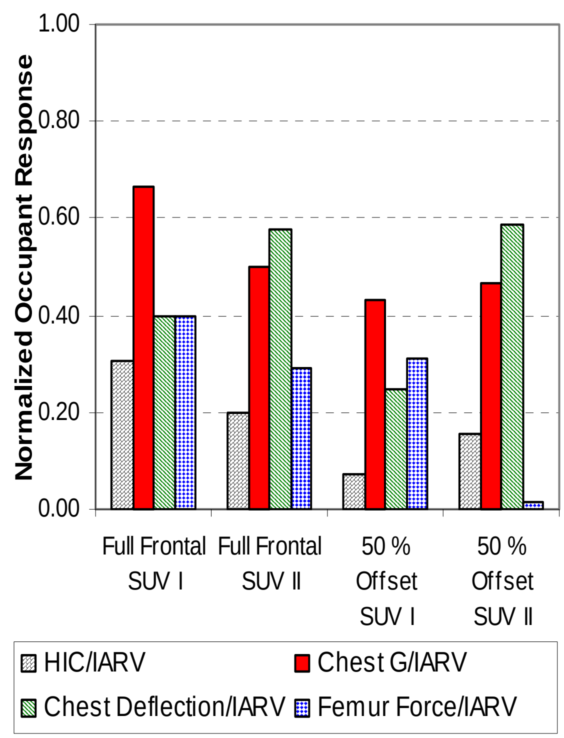


Figure 12. Occupant responses for passenger of the bullet vehicle.

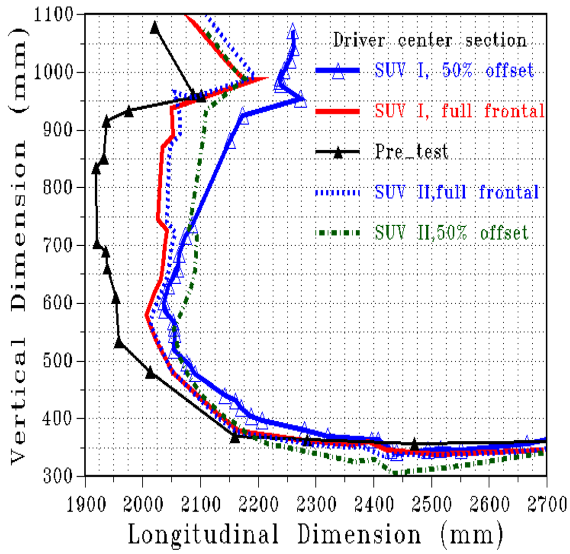


Figure 13. Comparison of dash intrusions in the target vehicle struck by SUV I and SUV II.

4. EFFECT OF COLLISION TYPE IN VEHICLE-TO-VEHICLE IMPACT

The same target vehicle, Mid-size car, was used in all the tests involved in this study. The same bullet vehicle, referenced by the "Small SUV" or "SUV I," was used to strike the target vehicle in (1) full frontal collinear, (2) 50% offset collinear, and (3) 30-degree oblique offset as shown in Figure 14. This selection provided the opportunity to investigate the effect of collision types on vehicle compatibility. Table 7 shows the mass ratio, initial impact speed, and velocity changes associated with the three different test configurations.

Table 7.

Mass Ratios, Impact Speeds and Velocity Changes in Each Test

Impact Configuration		Full Frontal Collinear	50 % Offset Collinear	30 dg. Oblique Offset
Bullet Vehicle Mass	kg	2132	2131	2084
Target Vehicle Mass	kg	1867	1859	1845
Mass Ratio		1.14	1.15	1.13
Bullet/Target Initial Speed	kph	95 / 0	94.9 / 0	56.4 / 57.2
T\Velocity Change	kph	51	51.8	57
B\Velocity Change	kph	47	44.6	58.2

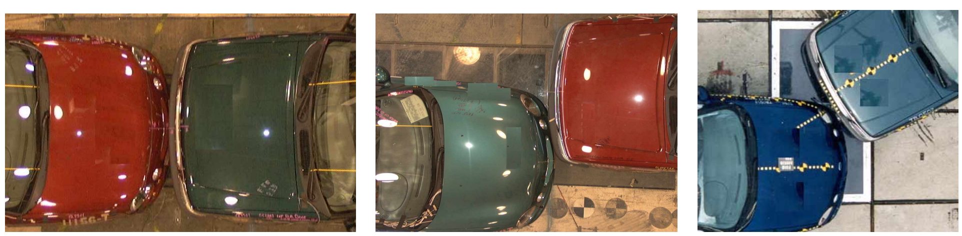


Figure 14. Vehicle-to-vehicle test configurations.

4.1 Occupant Response Comparison

The occupant response results for the occupants of the target vehicle in full frontal collinear, 50% offset collinear and 30-degree oblique offset crash tests are presented in Table 8 and Figures 15 and 17. Similar responses associated with occupants of the bullet vehicle are also presented in Table 9 and Figures 16 and 18. The performance of the occupants in the target vehicle varied significantly with the type of impact configuration. As shown in Figure 15, none of the IARVs were exceeded in the collinear impact tests while two out of four IARVs were exceeded and the other two were marginal in the oblique offset test. The overall deformation mode shown in Figure 19 was a clear explanation for these results. In the oblique test, only the driver-side front corner engaged with the bullet vehicle. The energy absorbing structure of the target vehicle completely missed structural interaction with the bullet front end. In addition, the geometrical incompatibility between both vehicles resulted in the bullet vehicle overriding the target vehicle towards the driver A-Pillar of the target vehicle. This over-ride resulted in considerably higher intrusions in the occupant compartment. This intrusion caused significant rearward movements of the base of the A-pillar at the windshield and the center of the steering wheel. This resulted in significantly higher chest deflections, chest accelerations, and femur loads.

The occupant responses of the passenger of the target vehicle appeared to be higher in the full frontal compared to those in 50% offset and 30-degree oblique (see Figure 17). This was not surprising since the passenger of the target vehicle engaged less with the impact in the 50% offset and oblique tests. However, all the occupant responses for the occupants of the bullet vehicle were below the IARVs.

Table 8.

Driver Dummy Responses in Target and Bullet Vehicle in Various Impact Configurations

			Occupant Responses for Driver in Target Vehicle			Occupant Responses for Driver in Bullet Vehicle		
Collision Type		IARV	Full Frontal	50 % Offset	30-dg. Oblique	Full Frontal	50 % Offset	30-dg. Oblique
Occupant Responses		Ref[9]	***Driver 50th Percentile Male***			***Driver 50th Percentile Male***		
HIC		1000	531	386	931	327	148	234
Chest Acceleration	G	60	52	49	119	47	30	36
Chest Deflection	mm	63	45	43	56	34	19	25
L/Femur Compression	N	10,000	3576	5716	22347	6783	3376	2608
R/Femur Compression	N	10,000	5235	6837	8153	3821	2793	5241
R/Tibia Index, Driver		1	0.65	0.81	1.16	0.37	0.43	0.56
L/Tibia Index, Driver		1	0.55	1.00	0.90	0.26	0.36	0.68

Table 9.

Passenger Dummy Responses in Target and Bullet Vehicle in Various Impact Configurations

			Occupant Responses for Passenger in Target Vehicle			Occupant Responses for Passenger in Bullet Vehicle		
Collision Type		IARV	Full Frontal	50 % Offset	30-dg. Oblique	Full Frontal	50 % Offset	30-dg. Oblique
Occupant Responses		Ref[9]	***Passenger 5th Percentile Female***			***Passenger 5th Percentile Female***		
HIC		1000	349	125	355	307	72	76
Chest Acceleration	G	60	40	29	36	40	26	31
Chest Deflection	mm	52	24	17	16	21	13	20
L/Femur Compression	N	6,800	4977	3109	3734	2366	2126	2138
R/Femur Compression	N	6,800	4323	1939	1511	2695	2059	1601
R/Tibia Index, Driver		1	-	0.14	0.72	-	0.10	0.13
L/Tibia Index, Driver		1	-	0.15	0.12	-	0.16	0.13

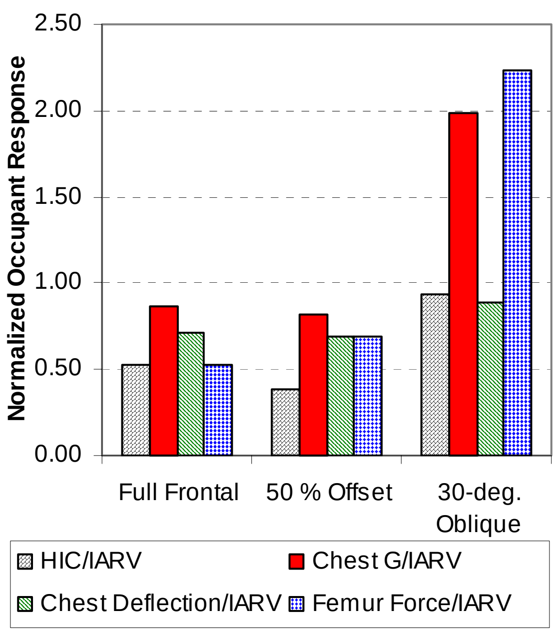


Figure 15. Occupant responses for driver of the target vehicle.

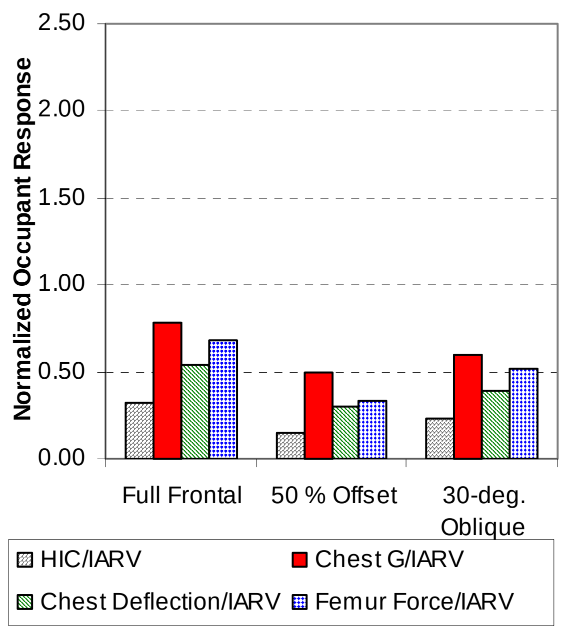


Figure 16. Occupant responses for driver of the bullet vehicle.

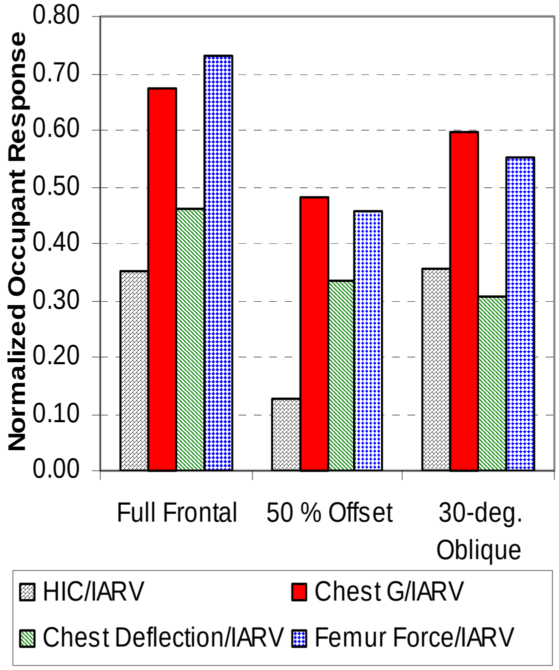


Figure 17. Occupant responses for passenger of the target vehicle

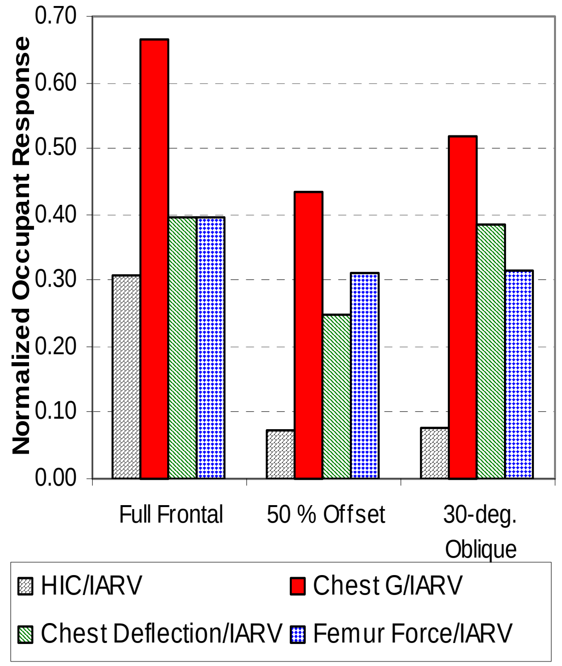
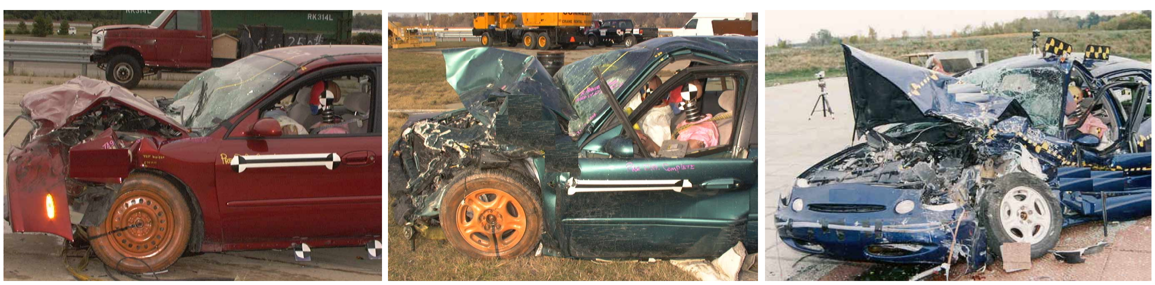


Figure 18. Occupant responses for passenger of the bullet vehicle



Full frontal collinear **50 % offset collinear** **30-degree oblique offset**

Figure 19. The overall deformations in the three types of impact tests.

5. CONCLUSIONS

- In the 30-degree oblique offset tests, it was difficult to extract the effect of vehicle design parameters such as mass, stiffness, and geometry, on vehicle compatibility.
- It was also concluded that this type of test configuration resulted in unacceptable test-to-test repeatability and reproducibility, and vehicle trajectories were sensitive to initial contact points.
- In the 30-degree oblique tests, the occupant responses in the target vehicle correlated well with both the vehicle mass and aggressivity metric of the bullet vehicle.
- An alternative compatibility test procedure consisting full frontal and 50% offset collinear impact was deemed more practical in terms of intrusion limits, occupant responses, and repeatability.
- Results indicated that geometrical compatibility was a necessary design feature in order to achieve compatibility in the fleet. Moreover, the effect of geometry was shown to possibly reduce the effects of mass and stiffness.

6. ACKNOWLEDGEMENT

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